Distinguishing RBL-like objects and XBL-like objects with the peak emission frequency of the overall energy spectrum

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Abstract

We investigate quantitatively how the peak emission frequency of the overall energy spectrum is at work in distinguishing RBL-like and XBL-like objects. We employ the sample of Giommi et al. (1995) to study the distribution of BL Lacertae objects with various locations of the cutoff of the overall energy spectrum. We find that the sources with the cutoff located at lower frequency are indeed sited in the RBL region of the $\alpha_{ro} - \alpha_{ox}$ plane, while those with the cutoff located at higher frequency are distributed in the XBL region. For a more quantitative study, we employ the BL Lacertae samples presented by Sambruna et al. (1996), where, the peak emission frequency, ν_p, of each source is estimated by fitting the data with a parabolic function. In the plot of $\alpha_{rx} - \log \nu_p$ we find that, in the four different regions divided by the $\alpha_{rx} = 0.75$ line and the $\log \nu_p = 14.7$ line, all the RBL-like objects are inside the upper left region, while most XBL-like objects are within the lower right region. A few sources are located in the lower left region. No sources are in the upper right region. This result is rather quantitative. It provides an evidence supporting what Giommi et al. (1995) suggested: RBL-like and XBL-like objects can be distinguished by the difference of the peak emission frequency of the overall energy spectrum.

1 Introduction

BL Lacertae objects have been mostly observed and identified in either radio or X-ray surveys. Radio selected BL Lacertae objects (RBLs) differ from X-ray selected BL Lacertae objects (XBLs) in many aspects. For example, in radio band, XBLs tend to have weaker cores and they are less core-dominated than RBLs (see Perlman & Stocke 1993), while in optical band, XBLs are less variable and less polarized than most RBLs (see Jannuzi et al. 1994). Most importantly, more and more studies confirm the fact that RBLs and XBLs occupy different regions on the $\alpha_{ro} - \alpha_{ox}$ plane, suggesting that these two groups of objects have significantly different overall spectral energy distributions (see, e.g., Ledden & O'Dell 1985; Stocke et al. 1985; Giommi et al. 1990). According to Padovani & Giommi (1995), no explanation of this fact has been given within the different viewing angle hypothesis so far. In studying the shape of the radio to X-ray spectrum of a large sample of BL Lacertae objects, Giommi et al. (1995) found that RBLs are characterized by an energy spectrum with a sharp cutoff in the IR-to-optical band while in most of XBLs the turnover is located near the UV-to-X-ray band or at higher frequencies. By assuming that the wavelength of the peak of the synchrotron emission changes smoothly and continuously from X-ray band to infrared band for BL Lacertae objects, the radio-to-optical-to-X-ray colors of RBLs and XBLs can be reproduced and then explained easily (Padovani & Giommi 1995; Urry & Padovani 1995). Padovani & Giommi (1996) discovered from the X-ray spectra of 85 BL Lacertae objects that there are significant differences between the two classes of the objects. For XBL-like objects, the X-ray spectral slope is anti-correlated with the peak emission frequency of the spectrum, while for RBL-like objects, there is a weak positive correlation between the two quantities. They found that the observed differences come mainly from the location of the peak emission frequency of the energy spectrum. Lamer et al. (1996) got a similar result in their study of soft X-ray spectra of 74 BL Lacertae objects. These imply that the location of the peak emission frequency of the overall energy spectrum of BL Lacertae objects may be an important quantity comparable to the radio-to-X-ray spectral index α_{rx} to distinguish RBL-like and XBL-like objects.

Empirically, the frequency where the cutoff of the overall energy spectrum of a source occurs is also the peak emission frequency of the spectrum when all the data from radio to X-ray band are presented and plotted. In this paper, the term "the cutoff of the overall energy spectrum" is used when we deal with only a few observational data of a source, such as that in Giommi et al.

(1995). When the term "the peak emission frequency of the spectrum" is used, we deal with the entire energy spectrum (from radio to X-ray) of a source.

2 The role of the cutoff of the overall spectrum

In this section, we investigate how the location of the cutoff of the overall energy spectrum is at work in distinguishing the two classes of BL Lacertae objects, that of RBL-like and XBL-like. According to the study of Giommi et al. (1995), we expect that, in the $\alpha_{ro} - \alpha_{ox}$ plane, the BL Lacertae objects with a cutoff in IR-to-optical band and those with a cutoff in UV-to-X-ray band will be distributed in two distinctive areas which might be defined as RBL and XBL regions respectively.

There are 121 sources in the sample of Giommi et al. (1995). In this sample, there are only 103 sources with all the values of radio, optical and X-ray fluxes being available. We find from Table 5 of Giommi et al. (1995) that, for these 103 sources, the number of the ones with the cutoff of the overall energy spectrum located at $2.4 \times 10^{17} Hz \leq \nu_p \leq 4.8 \times 10^{17} Hz$ is 36, while that of $5.5 \times 10^{14} Hz \leq \nu_p \leq 6.8 \times 10^{14} Hz$ is 60 and that of $5.0 \times 10^{12} Hz \leq \nu_p \leq 2.5 \times 10^{13} Hz$ is 7. We assign f_{5GHz}, $f_{5500\mathring{A}}$ and f_{2keV} to radio, optical and X-ray fluxes, respectively. When available, mean values of these fluxes are adopted. When converting other X-ray fluxes to f_{2keV}, we follow Giommi et al. (1995) to take $\alpha_x = 1.0$ ($f_\nu \propto \nu^{-\alpha}$). The spectral indices α_{ro}, α_{ox} and α_{rx} for these sources are calculated with $\alpha_{ro} = \log(f_{5GHz}/f_{5500\mathring{A}})/5.04$, $\alpha_{ox} = \log(f_{5500\mathring{A}}/f_{2keV})/2.94$ and $\alpha_{rx} = \log(f_{5GHz}/f_{2keV})/7.99$, respectively.

The K-correction is ignored due to the fact that the effect is small. There are 71 of the 103 sources with their redshifts being available and certain. We adopt $\alpha_r = 0.35$, $\alpha_o = 0.5$ and $\alpha_x = 1.0$ to calculate the K-corrected spectral indices α^k_{ro}, α^k_{ox} and α^k_{rx} for these 71 sources. Defining $\triangle\alpha_{ij} \equiv \alpha_{ij} - \alpha^k_{ij}$, we find $(\triangle\alpha_{ro})_{\max} = 0.009$, $(\triangle\alpha_{ox})_{\max} = 0.049$ and $(\triangle\alpha_{rx})_{\max} = 0.023$ among these sources. It indicates that, for the above sample, the effect would not significantly affect the location of a source in the $\alpha_{ro} - \alpha_{ox}$ plane (see Figure 1).

Figure 1 shows that, in the $\alpha_{ro} - \alpha_{ox}$ plane, the 7 sources with $5.0 \times 10^{12} Hz \leq \nu_p \leq 2.5 \times 10^{13} Hz$ are located in the RBL region (where $\alpha_{rx} > 0.75$) and the 36 sources with $2.4 \times 10^{17} Hz \leq \nu_p \leq 4.8 \times 10^{17} Hz$ are distributed in the XBL region (where $\alpha_{rx} \leq 0.75$), while the 60 sources with $5.5 \times 10^{14} Hz \leq \nu_p \leq 6.8 \times 10^{14} Hz$ are scattered in both RBL and XBL regions. Meeting exactly what we expect, the sources with the cutoff located at lower frequency are indeed sited in the RBL region while those with the cutoff located at higher frequency are distributed in the XBL region. Recalling that there are no sufficient data within optical-to-X-ray band presented in the sample, the scatter of the 60 sources with $5.5 \times 10^{14} Hz \leq \nu_p \leq 6.8 \times 10^{14} Hz$ is understandable. Many of them may probably be those with the cutoff located in UV band. It is probable that, when sufficient data in UV-to-soft-X-ray band are available, the above scatter will decrease.

Padovani & Giommi (1996) pointed out that, for XBL-like objects, α_x is correlated with α_{ox} with a best fit $\alpha_x = (1.38 \pm 0.20)\alpha_{ox} - (0.01 \pm 0.22)$, while for RBL-like objects, the two quantities are not correlated. As mentioned above, when converting other X-ray fluxes to f_{2keV} to calculate α_{ox} we adopt $\alpha_x = 1.0$. Would this significantly affect the distribution of the objects shown in Figure 1? Among the XBL-like objects (defined by $\alpha_{rx} \leq 0.75$) in the figure, the largest value of α_{ox} is 1.34 and the smallest one is 0.488. According to the relation of α_x and α_{ox} got by Padovani & Giommi (1996), the two values of α_{ox} correspond to $\alpha_{x,max} = 1.85$ and $\alpha_{x,min} = 0.673$, respectively. When converting f_{1keV} to f_{2keV} by adopting $\alpha_x = 1.0$, the corresponding errors $\triangle\alpha_{ox} \equiv \alpha_{ox} - \alpha_{ox,0}$ (where α_{ox} is valued by adopting the real value of α_x and $\alpha_{ox,0}$ is valued by adopting $\alpha_x = 1.0$) would be -0.087 and 0.033, respectively. It suggests that, in Figure 1, when corrected by this effect, the rightward XBL-like objects would move slightly leftward and the leftward ones would move slightly rightward. It would not significantly affect the distribution of the objects.

3 The plot of the radio-to-X-ray index versus the peak emission frequency

Sambruna et al. (1996) collected nonsimultaneous radio, infrared, optical and X-ray fluxes for three complete samples of blazars to study the properties of their spectra. In their study, the peak emission frequency of each source is estimated by fitting the data of the source with a parabolic function. The values so obtained must more or less reflect the real values of the peak emission frequencies, since the estimation comes from fitting. An advantage of these values is that they may be slightly different from source to source, unlike those of the cutoff of the overall energy spectrum obtained directly from Table 5 of Giommi et al. (1995), where, only a few separate values are available. For this reason, these values may be useful for a more quantitative study. The values of the radio-to-X-ray index α_{rx} and the peak emission frequency ν_p for the three samples are presented in Table 2 of Sambruna et al. (1996). All these values have been K-corrected. We adopt only the RBL and XBL samples to study in this paper. The plot of $\alpha_{rx} - \log \nu_p$ is shown in Figure 2. In Figure 4 of Sambruna et al. (1996), the solid line is the parabolic fit to the individual spectral energy distributions including the X-ray data point and the dashed line is the parabolic fit excluding this point. Among the sources with dashed lines, two are those with their parabolic lines being above the X-ray data points and the others are those with their parabolic lines being under the X-ray data points. We use the filled, empty and empty plus cross symbols to represent the sources with solid lines, the dashed lines under the X-ray data points and the dashed lines above the X-ray data points, respectively, in Figure 2. In this figure, the $\alpha_{rx} = 0.75$ line and the $\log \nu_p = 14.7$ line divide the $\alpha_{rx} - \log \nu_p$ plane into four different regions. All the RBL-like objects, defined by $\alpha_{rx} > 0.75$, are inside the upper left region, while most XBL-like objects, defined by $\alpha_{rx} \leq 0.75$, are within the lower right region. Those in the lower left region are all the sources with their parabolic lines being under the X-ray data points in Figure 4 of Sambruna et al. (1996). There are no sources in the upper right region. Excluding all the sources with their fitted parabolic lines not passing through the X-ray data points, those are represented by empty and empty plus cross symbols, we find from Figure 2 that RBL-like objects and XBL-like objects are well separated by the $\alpha_{rx} = 0.75$ line and the $\log \nu_p = 14.7$ line, and well confined in two different regions. It is known that three points of data correspond to a single parabolic line. In the plots drawn in Figure 4 of Sambruna et al. (1996), given two leftward points of data, $(\nu_r, \nu_r L_r)$ and $(\nu_o, \nu_o L_o)$, a larger value of $\nu_x L_x$ for the rightward point of data, $(\nu_x, \nu_x L_x)$, would yield a larger value of ν_p than a smaller value of $\nu_x L_x$ does. Therefore, when corrected by adjusting the parabolic lines passing through the X-ray data points, all the empty symbols in Figure 2 will move rightward and all the empty plus cross symbols will certainly move leftward (a detailed study of this issue is in preparation). The above result is rather quantitative. It provides an evidence supporting what Giommi et al. (1995) suggested: RBL-like and XBL-like objects can be distinguished by the difference of the peak emission frequency of the overall energy spectrum.

4 Discussion and conclusions

To investigate quantitatively how the peak emission frequency of the overall energy spectrum is at work, we employ the estimated values of the quantity to study. It shows that, in the plot of

$\alpha_{rx} - \log \nu_p$, RBL-like objects and XBL-like objects are well separated by the two lines of $\alpha_{rx} = 0.75$ and $\log \nu_p = 14.7$. The two kinds of objects are well confined in two different regions. Is this result trivial? Can the value of ν_p be solely determined by α_{rx}? Our answer is no. Given only the values of radio and X-ray fluxes, f_r and f_x, α_{rx} is uniquely determined, but ν_p is not. It is because that there are countless parabolic lines passing through f_r and f_x. Therefore, α_{rx} can not solely determine the value of ν_p. To yield a single parabolic line, one needs all the values of f_r, f_o and f_x, where f_o is the optical flux, [see Equation (2) of Sambruna et al. 1996]. We then reach the conclusion that the above result is not trivial. In fact, given a certain value of α_{rx}, different ν_p will correspond to different f_o. The quantity ν_p reflects the relation between f_r and f_o or f_o and f_x.

We notice that the value of ν_p determined by a parabolic function fitting the values of f_r, f_o and f_x is not necessarily the real value of the peak frequency of the synchrotron emission. This is because that the shape of the overall energy spectrum is not simply a parabolic line passing through f_r, f_o and f_x for many sources. Their overall spectra may be contributed by both synchrotron emission and Compton scattering of lower-energy seed photons (see Figure 6 of Ulrich et al. 1997). Therefore, we do not consider the peak emission frequency ν_p in Sambruna et al. (1996) as the real peak frequency of the synchrotron emission. Instead, we think of the frequency ν_p as a measure of the relation between f_r and f_o or f_o and f_x. For such a measurement, we prefer ν_p to α_{ro} and α_{ox} due to the fact that, for RBL-like and XBL-like objects, the domains of ν_p are well separated, while the domains of α_{ro}, as well as α_{ox}, are overlapped (see, e.g., Figure 12 of Padovani & Giommi 1995).

We then come to the following conclusions. (1) This paper gives a rather quantitative result which provides an evidence supporting what Giommi et al. (1995) suggested: RBL-like and XBL-like objects can be distinguished by the difference of the peak emission frequency of the overall energy spectrum. (2) The peak emission frequency of a fitted parabolic function may be an essential quantity comparable to the radio-to-X-ray spectral index α_{rx} in distinguishing RBL-like and XBL-like objects. The division line is probably the $\log \nu_p = 14.7$ line. (3) The $\alpha_{rx} = 0.75$ line together with the $\log \nu_p = 14.7$ line are found to divide the $\alpha_{rx} - \log \nu_p$ plane into four different regions, where RBL-like objects are well inside the upper left region and most XBL-like objects are within the lower right region.

So, we agree with the suggestion of Padovani & Giommi (1995) that the names for the two

BL Lac classes, radio-selected and X-ray-selected BL Lacs (RBLs and XBLs), be replaced by the more physical ones, low-energy cutoff BL Lacs (LBLs) and high-energy cutoff BL Lacs (HBLs), respectively.

We suspect that, in the $\alpha_{rx} - \log \nu_p$ plane, while probably all the RBL-like objects are inside the upper left region and all the XBL-like objects are confined in the lower right region, those in the upper right region or lower left region may be: (1) (if it exists) the intermediate BL Lacertae objects (IBLs) connecting RBL-like objects and XBL-like objects; (2) the sources with their parabolic lines not passing through all the values of f_r, f_o and f_x (as those shown in Figure 2); (3) the sources with some of their fluxes being badly measured; (4) some extreme BL Lacertae objects; (5) the sources not belonging to BL Lacertae objects.

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Figure caption:

Figure 1: The $\alpha_{ro} - \alpha_{ox}$ diagram of BL Lacertae objects for the sample of Giommi et al. (1995). Open circles represent the 36 sources with $2.4\times10^{17} Hz \leq \nu_p \leq 4.8\times10^{17} Hz$, open squares represent the 7 sources with $5.0 \times 10^{12} Hz \leq \nu_p \leq 2.5 \times 10^{13} Hz$, and filled diamonds represent the 60 sources with $5.5 \times 10^{14} Hz \leq \nu_p \leq 6.8 \times 10^{14} Hz$. The solid line is the $\alpha_{rx} = 0.75$ line.

Figure 2: The plot of $\alpha_{rx} - \log \nu_p$ for the RBL and XBL samples presented by Sambruna et al. (1996). Circles represent XBLs and squares represent RBLs of the samples. Represented by empty symbols are the sources with their parabolic lines being under the X-ray data points. The empty plus cross symbols stand for the sources with their parabolic lines being above the X-ray data points. The dashed horizontal line is the $\alpha_{rx} = 0.75$ line and the dashed vertical line is the $\log \nu_p = 14.7$ line.